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THE EFFECT OF STRUCTURED CONTEXTUAL TONES ON

PSYCHOPHYSICAL FREQUENCY DISCRIMINATION

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Six musically and six non-musically trained observers listened to patterns composed of 11 tones of short duration (40 ms). Using a same-different psychophysical procedure observers were asked to report frequency changes in the middle tone of the pattern. Three experimental conditions were formed: constant, random, and structured. In the constant condition observers listened to a single pattern. The observers ———

in the structured and random conditions listened to 12 patterns, but the tonal patterns in the structured condition were arranged to reflect structural rules. Musical training made no difference, but magnitude of the frequency change was highly significant in discrimination performance. A non-parametric statistical analysis revealed a significant effect among the three conditions. It was demonstrated that a structured pattern of tones provided a knowledge source from which observers could effectively abstract information for frequency discrimination judgements.

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The Effect of Structured Contextual Tones on

Psychophysical Frequency Discrimination

Recent research has investigated the relative contribution of an individual's knowledge of events and the actual sensory input in perceptual processing. It is generally agreed that in the perception of speech there must be an interaction between these two sources of information since sensory data alone cannot be sufficient for the comprehension of fluent speech. Our internal knowledge of language and its rules makes a significant contribution to what we hear in speech (Marlsen-Wilson & Tyler, 1980; Marlsen-Wilson & Welsh, 1978). This interaction also has been illustrated in other areas. Knowledge in the form of grammatical structure has been shown to facilitate the classification of visual letter patterns (Reber, 1969, 1976; Reber & Allen, 1978; Reber & Lewis, 1977) and complex nonspeech patterns (Deutsch, 1980; Dewar, Cuddy & Mewhort, 1977; Howard & Ballas, 1980).

In the majority of these studies the experimental task involves the classification of entire patterns. Relatively little research has focused on the role of top-down and bottom-up processing in the resolution of individual components of multi-component patterns. This paper will address the issue by investigating how a higher level pattern structure influences the ability to discriminate changes in the frequency of a single element of eleven-component, pure-tone patterns.

Top Down Processing in Speech Perception

The most direct evidence for the existence of top-down (knowledge-driven) and bottom-up (data-driven) processes is found in the speech perception literature. There is little doubt that these two processes interact and, in

fact, are dependent. To illustrate this point consider a purely bottom-up model of speech perception. In such a model speech perception can be viewed as a series of steps starting with an auditory input and ending with a mental representation of what has been said. Phonemes are pulled from the speech waveforms by feature extraction or a similar process. The consonants and vowels are combined to form syllables; meanings are then retrieved from memory.   The important aspect of this model of speech perception is its unidirectional nature. Inputs in the process are only permitted from lower to higher analytical levels.

This model of perception has difficulties from the outset. Spectrograms of speech waveforms show a lack of segmentation that is assumed in the model. Word boundaries are slurred and often the segmentation expected between words actually occurs within words.   In addition, sounds at the lowest level are subject to contextual constraints. The actual sound of a consonant is dependent upon   other   phonemes in the syllable (Liberman, Cooper, Shankweiler, & Studdert-Kennedy, 1967). In fact, silence can be perceived as a consonant. Bastian, Eimas, and Liberman (1961) show that observers interpret the word "sore" as "store" when a short interval of silence is placed between the "s" and "o."

Several studies have shown that contextual information at higher analytical levels can also influence perception of speech. Marslen-Wilson (1975) employed a shadowing task to investigate perception of mispronounced words.   Observers were asked to repeat passages varying in syntactic and semantic congruence. In congruent passages the observers restored mispronounced words to their expected forms.   This suggests that higher order contextual information influenced lower level processes. To investigate the possibility that the mispronunciations were

perceived and then corrected, Marslen-Wilson and Welsh (1978) recorded observer response times. The latencies for correct and mispronounced words were not different, suggesting that perceptual and not conscious restoration processes were responsible for the corrections.

Perhaps the most striking example of the power of contextual information is shown in the research of Warren and his colleagues. Warren deleted a phoneme from a word and replaced it with the nonspeech sound of a "cough" or a pure tone (Warren, 1970). After listening to the word in a sentence most individuals reported that that no mispronunciations were present, even though they were asked to listen for and localize such occurrences.

Using this "phoneme restoration" effect Warren and Warren (1970) demonstrate that a partially ambiguous word can be interpreted in a variety of ways, depending on the context. They presented the sentence "It was found that the *eel was on the " to observers with one of four words spliced onto the end: axle, shoe, table, or orange. Depending on the final word the same sound pattern (*) was perceived as "wh," "h," "m," or "p."

These research findings strongly support the belief that both top-down and bottom-up processes exist in the perception of fluent speech. The bottom-up model of speech perception presented earlier must be modified to include the influence of higher order processes. Our knowledge of the rules and expectancies of language influence what we actually perceive by guiding "the construction of the representation of the speech input" (Glass, Holyoak, & Santa, 1979, p. 51).

Some of the top-down processes in speech perception can be defined. These are the phonologic, prosodic, semantic and syntactic rules of speech, as well as contextual cues which form expectancies in a conversation. Researchers in the

artificial intelligence area of automatic speech understanding have renamed these rules and expectancies "knowledge sources" (Reddy, 1976). In the HEARSAY II speech understanding system these knowledge sources can be added or deleted, thereby increasing or decreasing system performance levels (Reddy, Erman, & Neely, 1973; Lesser, Fennell, Erman, & Reddy, 1975). This conceptualization of available knowledge is quite useful in discussing top-down and bottom-up processing and will be used throughout the remainder of the paper.

Top-down Processing In Classification Of Entire Patterns

Although not as conclusive as the case for speech perception, there is also evidence pointing to the existence of top-down and bottom-up processing in other modes of perception. Reber (Reber, 1969, 1976; Reber & Allen, 1978; Reber & Lewis, 1977) has shown that top-down processes are evident in visual classification tasks. Listeners were asked to classify letter patterns as either grammatical or non-grammatical. The grammatical patterns were generated by a transition code which determined the sequential order of letters in the letter strings. The classification of grammatical patterns was consistently better than the classification of nongrammatical ones. This suggests that observers were able to abstract knowledge from the structure imposed by the transition code and use it in a top-down process for improved classification.

Reber and his colleagues have coined the phrase "implicit learning" for this process, since there are distinctions between it and normal learning. First, the rules must be abstract or complex. Second, the learning takes place outside the consciousness of the observer; an attempt to consciously formulate the rules impedes performance. This does not mean that implicitly learned knowledge sources cannot be utilized for performing tasks, rather it means that individuals have difficulty explaining the exact rules constituting the

knowledge source.   Reber et al. (1978, p. 191) describe implicit learning as "an hypothesized abstraction process, a nonconscious, nonrational, automatic process whereby the structural nature of the stimulus environment is mapped into the mind of the attentive subject."

Using a similar finite-state transition code Howard and Ballas (1980) extended Reber's work by demonstrating that top-down processes are also present in perception of non-speech sounds. Auditory patterns were constructed with either pure tones or complex "environmental" sounds such as a pipe clang or steam hiss. Patterns with syntactic structure (transition code) were classified better than those without structure, especially when the patterns were composed of pure tones. For complex tones, syntactic and semantic structure (thematic instructions) produced an interaction effect: when the sounds were interpretable (occurring in an order consistent with semantic associations) performance was improved by thematic instructions.

These findings indicate that top-down processing can occur in the classification of nonspeech sounds. The Reber studies, as well as that of Howard & Ballas, indicate that top-down processing occurs when an entire pattern is the experimental focus. Can top-down processing occur in simple, nonspeech patterns when the experimental task concerns an individual element of the pattern, rather than the pattern as a whole? The literature suggests that this may be the case.

Auditory Stream Segregation

An interesting and pervasive auditory phenomenon occurs in continuously and rapidly presented tones of sufficient frequency separation. The tones separate into similar "streams" or "channels" which are perceived as simultaneous and independent, rather than temporally alternating. An analogy from visual

perception is the Necker cube which can be seen from two possible perspectives, but only one at a time. Similarly, observers listening to a streamed auditory pattern can focus their attention on individual streams but not on the relationships of the pattern as a whole. This phenomenon has been alternately referred to as the trill threshold (Miller & Heise, 1950), rhythmic fission (Dowling, 1978), or auditory stream segregation (Bregman & Campbell, 1971). Miller and Heise (1950) initially illustrated the phenomenon by alternating two tones which gradually separated in frequency. At a separation of approximately three semitones the tones were perceived as simultaneous and independent rather than alternating.

Bregman and Campbell (1971) investigated these effects in tonal patterns composed of six elements. Alternate tones were selected from two frequency ranges and the resulting pattern was repeated continuously. Observers were asked to report the order of tones within the pattern, being given as much time as needed to reach a decision. Results indicate that reports of tone order within frequency ranges (streams) were accurate while those across ranges were not. In addition, observers tended to report tonal order in terms of streams and not the pattern as a whole. Bregman and Campbell stressed that the formation of streams results from an organizational process of perception not directly attributable to physical properties of the stimulus.

Subsequent research has expanded this theme. Bregman (1978) interprets this auditory streaming effect as a mechanism which assists in the sorting of the complex waveforms of audition. Although we may actually hear a conglomeration of sounds we perceptually sort or stream each component to its respective source. Howard and Ballas (1980) note that Bregman's work has concentrated on identifying the rules which govern auditory streaming at a basic

level. Using complex stimuli in the experiment previously discussed they have
shown that specific factors can also influence streaming. These factors include
"the listener's skills, intentions, and knowledge of the stimuli" (Howard &
Ballas, 1980, p. 432).

Effects of Structure on Pattern Perception

One aspect of auditory patterns that might be considered a higher level
factor is structure. Guilford (Guilford & Hilton, 1933; Guilford & Nelson,
1936) suggested that a rising or falling tone caused corresponding perceptual
changes in surrounding tones. Heise and Miller (1951) empirically tested this
observation by employing the auditory streaming effect. Patterns were organized
according to pitch in rising, falling, v-shaped (that is, falling, then rising
in pitch), or inverted v-shaped (rising, then falling) forms. The experimental
task was to increase or decrease the frequency of a single element until it
perceptually separated from the pattern. The overall tonal configuration was
found to influence perception, expecially in the v-shaped or inverted v-shaped
forms. In these patterns frequency alterations which sharpened the v's were
perceived more easily than those which flattened the V's.

Idson and Massaro (1976) also employed auditory streaming, along with
backward recognition masking, to show that pattern structure can influence
perception. The backward recognition masking effect (Massaro, 1970) involves
the presentation of a target tone followed by a masking tone. The ability to
recognize the first tone is correlated with the intertone interval: performance
increases with duration up to approximately 250 ms. Idson and Massaro
hypothesized that structure-induced auditory stream segregation in a pattern
might influence backward recognition masking since elements within a stream can
be related to each other while across-stream elements cannot be related (Bregman

& Campbell, 1971). As predicted, identification in patterns containing within-stream masks was lower than identification in those containing masks drawn from different octaves. When a single tone (instead of a pattern) and a mask from a different octave were presented, the backward masking effect was elicited.

Musical structure has been shown to influence performance in a variety of tasks (Attneave & Olson, 1971; Bartlett & Dowling, 1980; Cuddy, Cohen & Mewhort, 1981; Cuddy, Cohen, & Miller, 1979; Idson & Massaro, 1976; Krumhansl & Shepard, 1979). Musical structure includes the notion of scale and tonal relationship described in terms such as octave, tone chroma, diatonic, tonic, cadence, contour, and excursion (Deutsch, 1977; Dowling, 1978). Music theory suggests that the perception of melodies involves more than physically describable properties, such as cultural-bound schemata (Dowling, 1978).

Dewar, Cuddy, and Mewhort (1977) investigated the effects of pattern structure and contextual tones. Musical patterns containing 7 of 13 tones specific to an octave were chosen to constitute musical structure. The random assignment of seven tones in the octave constituted non-musical structure. Observers listened to a standard sequence and then chose between two alternatives, one of which was exactly the same. In the no context condition two individual tones were presented; in the full context condition two complete sequences were presented. The effects for both structure and context were highly significant, in favor of full context and musical structure.

Cuddy, Cohen, and Miller (1979) further delineate the role of structure in a melody transformation experiment. This task involves the relocation of an entire sequence to a higher or lower octave. Once relocated, a "target" trial consists of the _relative_ change in frequency of one element of the pattern. The

amount of musical structure was varied and performance was found to be directly related to the amount of musical structure present. Cuddy, Cohen and Mewhort (1981) used identical experimental procedures to extend the Cuddy et al. (1979) findings. Various amounts of sequence structure including harmonic structure and simple or complex contour were investigated. Again, performance was largely determined by the amount of musical structure present.

The experiments discussed in this section strongly suggest that contextual structure can provide a knowledge source for the abstraction of information. As we have seen, this information can be used in a variety of tasks to improve performance. One paradigm in which the effects of contextual structure are considered deleterious is that of Watson and his colleagues (Watson, Wroton, Kelly, & Benbassat, 1975; Watson, Kelly, & Wroton, 1976; Speigel & Watson, 1981). They state that "it appears to be the variation of the contextual pattern in which the signal is embedded which is associated with severe degradation of performance" (Watson et al., 1976, p. 1184). However, a deeper understanding of the paradigm is necessary to appreciate their use of the term "contextual pattern." Watson's paradigm employs highly trained (task-specific) observers who resolve patterns composed of extremely short-duration tones. Typically, an observer in such an experiment hears a small number of patterns on a large number of trials. A change in "contextual pattern" in this sense is simply how well an entire pattern is learned, rather than the structure of the elements which compose it.

Using these highly overlearned patterns, Watson and his colleagues have found that the overall uncertainty of how the "target tone" (i.e., tone subject to frequency change) can vary influences the listeners' ability to detect frequency change. They identify four factors which influence uncertainty in

single-tone frequency discrimination: 1) the number of patterns heard, 2) the number of target tone frequencies, 3) the number of target tone positions, and 4) the temporal position of the target tone. Of the four uncertainty variables, Watson argues that the number of patterns presented is the most influential factor in frequency discrimination.

The Structure of Individual Elements as a Knowledge Source

However, structure as individual elements of a pattern rather than a "contextual pattern" may also influence performance. The previously discussed literature suggests that this structure can provide a source of knowledge for top-down processing.   It is hypothesized that providing structure to tones surrounding the target tone will provide such a knowledge source and improve performance in the Watson paradigm. Three conditions will be arranged to test this hypothesis: a constant, a random, and a structured condition.   In the constant condition only one pattern will be played to listeners, while in the random and structured conditions 12 patterns will be played.   It is predicted that the constant condition will result in superior performance since there are fewer patterns and consequently less uncertainty, while the other three variables Watson cited are held to a minimum. For the structured and random conditions all four variables will be held constant. The only difference will be that the tones surrounding the tone subject to change will contain an inverted-v structure (rising and then falling in pitch) similar to the structure employed in the studies of Miller and Heise (1951). It is predicted that listeners will employ top-down processing in the structured condition to improve performance relative to the random condition.

The second experimental hypothesis concerns the effect of musical training. In experiments involving musically structured tones observers with musical

training typically perform better than untrained observers. For detecting correct melody transpositions the effect is quite pervasive (Attneave & Olson, 1971; Bartlett & Dowling, 1980; Cuddy, 1971; Cuddy & Cohen, 1976; Cuddy, Cohen, & Mewhort, 1981; Krumhansl & Shepard, 1979). As an example, Cuddy and Cohen (1976) asked both types of observers to discriminate between transpositions in which one tone was altered. Trained observers performed near the 90% discrimination level while untrained observers were not much above chance (60%).

The effect of musical training in other types of frequency discrimination is not so well defined. In absolute pitch judgement performance is correlated with musical training (Cuddy, 1968; Cuddy & Cohen, 1976). There is also evidence that frequency discrimination in patterns is affected by musical training. Dewar, Cuddy, and Mewhort (1977) found that in a two alternative forced-choice procedure musical training facilitated the ability to detect frequency changes. Using essentially the same paradigm, it is hypothesized that musical training will improve performance in the present study.

The third experimental prediction involves the factor of change magnitude. Since the observers in the present study will not have as much training as those of Watson's, the size changes will be increased by the order of one magnitude. It is predicted that observer performance will be directly related to absolute frequency change. No prediction is made on the basis of positive or negative changes.

Method

Participants

Twelve paid individuals served as listeners in the experiment. Musically trained listeners were recruited from the Catholic University School of Music.

No attempt was made to segregate the various disciplines within the field (voice majors, composers, etc.) or level of training. Nonmusically trained listeners either responded to advertisements or were recruited from a subject pool. Two musically and two nonmusically trained listeners were randomly assigned to each of the three conditions.

Stimuli

The patterns were composed of eleven tones played in succession with an intertone interval of 5 ms. The duration of each tone was 40 ms with a 2.5 ms rise/fall time. Fourteen different patterns were constructed by randomly choosing without replacement from tones of 500, 565, 638, 721, 815, 920, 1040, 1175, 1327, 1500, and 1673 Hz with the qualification that the 1673 Hz target tone and the tone occupying the sixth position were switched in each pattern. This allowed all patterns to have the target tone in the same temporal position. A pattern for the training session and a pattern for the constant condition were chosen randomly, with the remaining 12 forming the basis for both the random and structured conditions. To construct a structured pattern, the tones prior to the target tone in a random pattern were rearranged to ascend in frequency and the later tones were rearranged to descend in freq_* _y.

To generate a "different" pattern, the target tone was replaced with a tone having one of four frequency changes relative to the 1673 Hz: +32, -32, -48, or -64 Hz (see footnote). The patterns were presented at an approximate listening level of 76 dB SPL. Both the presentation of the same and different trials along with the size and direction of the change in frequency were varied randomly in experimental trials.

The training trials employed a variation of the "simulated method of

adjustment" used by Spiegel and Watson. The same and different trials were presented alternately. The different trials were constructed to illustrate explicitly what constituted a different trial. Eighteen differences ranging from 350 Hz above to 350 Hz below the target tone were used including the four differences to be used in the experiment. The presentation of differences was systematic, going from the largest to the smallest difference above the target tone, then proceeding from the smallest to the largest difference below.

Apparatus

All experimental events were controlled by a general purpose laboratory computer (Digital PDP/8e). The tones were synthesized with the computer using standard digital techniques. They were output on a 12-bit digital-to-analog converter at a sampling rate of 12.5 kHz, low-pass filtered at 3 kHz (Khron-Hite Model 3550), attenuated, and presented binaurally over matched Telephonics TDH-49 headphones with MX-41/AR cushions. Prompts were presented by a video monitor in the test booth and listeners indicated their responses by pressing buttons on a solid-state keyboard.

Procedure

Listeners were tested individually in a sound-attenuated booth for 1 hour on 5 consecutive days. The first session was devoted to training. The second session was 30 min of training followed by the first experimental block. Sessions 3 through 5 contained 5 min of training and 2 experimental blocks, resulting in a total of 7 data blocks for the experiment.

The instructions were explicit due to the difficult nature of the task. Before the first training session the listeners were informed that they would

hear auditory patterns composed of short tones played very quickly and that a pair of patterns would be presented together. They were told that the second pattern of the pair might be different and that this difference would only be found in the pitch of the sixth tone. A graphic illustration of a paired presentation was included. They were informed that same and different trials would alternate, that the changes were systematic and that their only task was to listen carefully to the patterns and how they were different. Before the first experimental block was presented another set of instructions was given indicating that same and different trials would be presented randomly and that it was their task to decide whether the patterns were the same or different. They were shown the possible responses and asked to let a numeric choice reflect their confidence in the decision. Any questions were answered. The instructions were identical for all groups.

A trial began when the word "listen" appeared on the screen. The first pattern and the second pattern were accompanied by the prompts "pattern 1" and "pattern 2" as they were played. These 6 choices immediately appeared on the screen following the prompts:

> 1=definitely different
>
> 2=probably different
>
> 3=possibly different
>
> 4=possibly the same
>
> 5=probably the same
>
> 6=definitely the same

After the listeners indicated their choice by pressing one of six buttons on the keyboard, immediate visual feedback was provided. After a 1.5 s intertrial interval the next trial began. The training program followed the

same procedure except that instead of response choices immediate visual feedback was provided after the patterns had been played. No listener response was required and a new trial began automatically. In the training session 432 paired pattern trials were given. In an experimental block each listener received 144 trials per session. Thus, each listener heard 1008 total test trials. Opportunities for two breaks were provided in each experimental session and in the hour long training session.

Results and Discussion

Listener confidence ratings were used to compute receiver-operating characteristics (ROC's). The area under a ROC yields a response-bias-free index of performance (Green & Swets, 1966). To assess the effect of the change in frequency differences, listener responses were collapsed across trials and ROC's were computed. A Change X Training X Group ANOVA was performed. The main effect of Change was highly significant, $F(3,18)= 6.58$, $p<.005$, while the main effect of Group was found to be not significant, $F(2,6)=3.87$, $p<.10$. Training had no effect, $F(1,6)=1.05$. No interactions were found to be significant: Training X Group, $F(2,6)=2.14$, $p<.20$, Change X Group, $F(6,18)=1.98$, $p<.20$, Change X Training, $F(3,18)=1.45$, and Change X Training X Group, $F(6,18)=1.32$.

In order to assess the effects of experience, listener responses were collapsed within experimental blocks and the corresponding ROC areas were computed. A Block X Training X Group ANOVA was then performed. The main effect of Group, $F(2,6)=3.47$, $p<.10$, was not significant while Training, $F(1,6)=.68$, and Block, $F(6,36)=1.51$, had no effect. No interactions were significant: Training X Group, $F(2,6)=2.04$, Block X Training, $F(6,36)=.38$, and Block X Training X Group, $F(12,36)=.40$.

The ROC areas were averaged across listeners within the three experimental

groups in each analysis and plotted. The Block X Group data are presented in Figure 1; the Change X Group data are presented in Figure 2. Both graphs reveal apparently consistent differences between groups which are only marginally indicated by the statistics employed. To investigate this discrepancy further the homogeneity of variance was tested. The Group variances in each analysis were subjected to the Hartley's Fmax test. For the Group X Block variances, Fmax = 3.24, $p<.05$; for the Change X Group variances, Fmax = 22.73, $p<.01$. In both instances an underlying assumption of ANOVA was violated for the main effect of Group.

To circumvent this problem a nonparametric Kruskal-Wallis ANOVA by ranks was performed. For each individual the results were averaged across blocks for an experiment-wide estimation of performance. (An averaging across the Change X Group data resulted in the same rankings.) These scores were then placed in rank order. The analysis indicated that the rankings were significantly different at an Alpha level of .05, H=6.75. This analysis allows the conclusion that the structured group performed significantly better than the random group as predicted.

Although this analysis does not permit claims of significant differences between the structured and constant groups, inspection of the graphs and rankings indicate that some difference does exist. This is surprising since Watson et al. (1976, p. 1183) found that "the largest change in performance associated with a single factor of stimulus uncertainty is that related to the number of patterns, or different tonal sequences, in the stimulus catalogue." Since the structured condition had 12 patterns while the constant condition had only one, these results are unexpected. In view of Watson's findings it was predicted that the observers in the constant condition would outperform
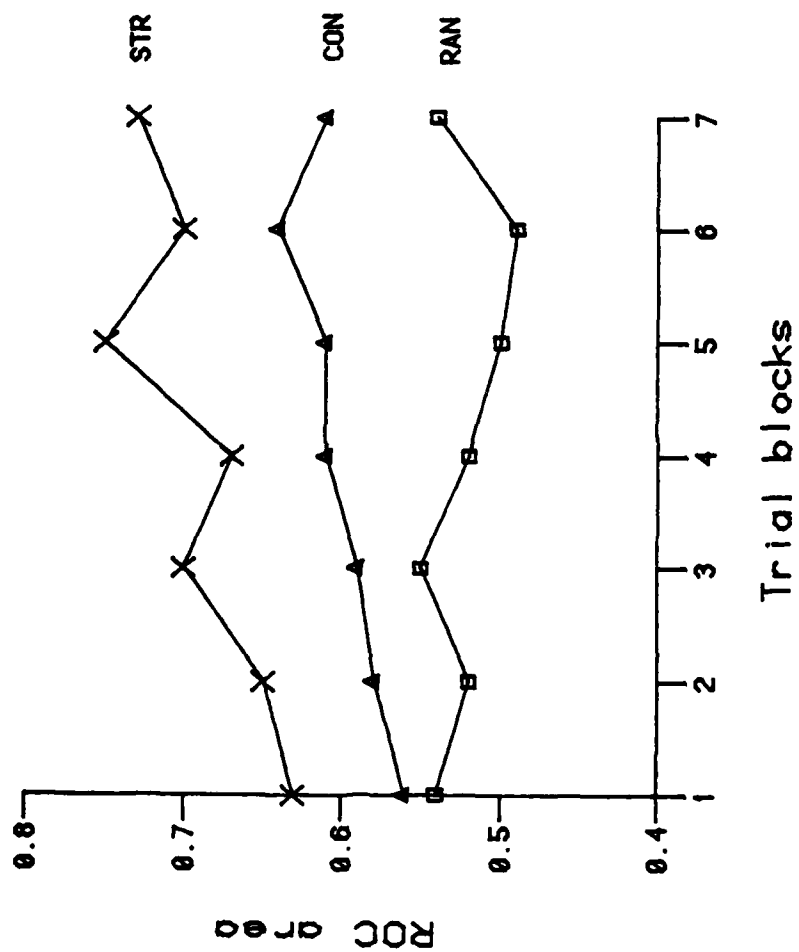
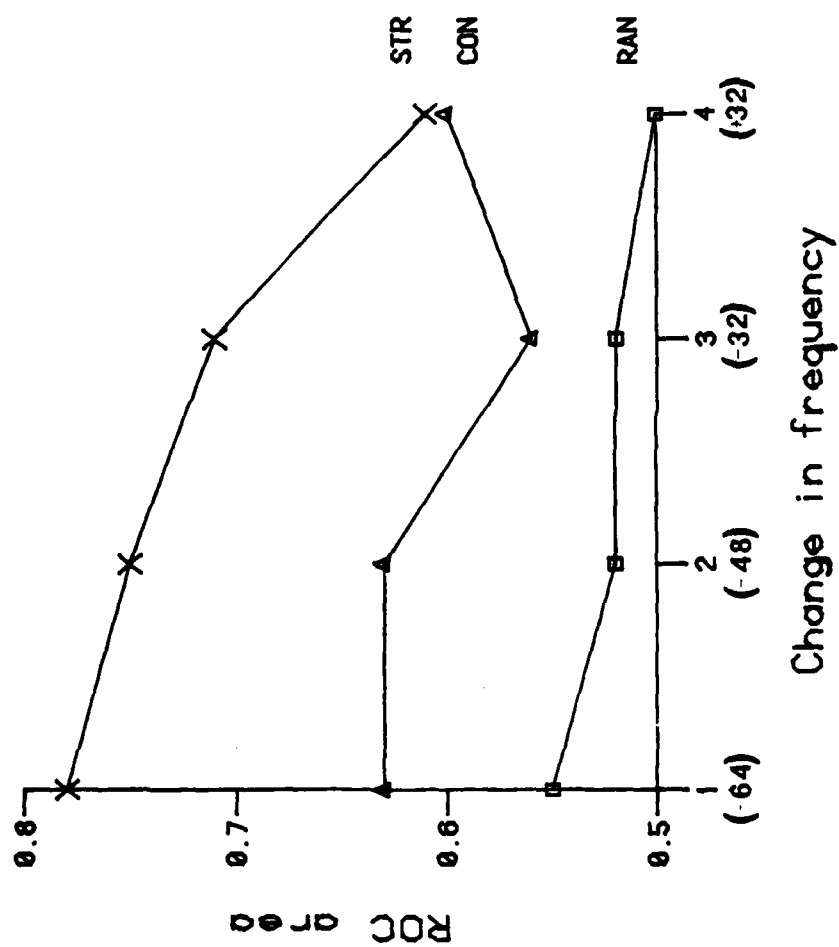Figure 1. Composite Block X Group Data

Figure 2. Composite Change X Group Data

observers in the structured condition.

The effect of musical training was virtually nonexistent. There are several possible explanations. First, the criteria for musical training was not as stringent in this study as in other studies. For example, Cuddy, Cohen and Mewhort (1981) separated trained and highly trained listeners on the basis of specific conservatory ratings and the number of instruments practiced on a regular basis. In the present study the musical training group included voice majors, and a composer as well as those who practiced instruments. Second, the experimental task differs from the majority of studies indicating effects due to musical training. These experiments measure performance on relative frequency changes through the melody transposition task.

Even in studies reporting musical effects with similar tasks there are differences in the nature of the stimuli. Dewar, Cuddy, and Mewhort (1977) report training effects in a study differing essentially in only three aspects: tone duration, type of tone, and definition of structure. The tones were generated on a piano and taped, whereas the present study employed pure tones. Also, the tones were much longer in that study, lasting 667 ms as opposed to 40 ms. Finally, the tones were chosen with musical structuring constraints. The absence of timbre and musical structure, as well as the short-duration of the tones in the current experiment certainly contribute to the absence of a musical training effect.

The primary purpose of the present experiment was to examine the role of top-down processing and knowledge sources in perception. The overall performance of the structured group indicates that these observers were able to extract information from the structure and use it in top-down processing. Some specific aspects of performance also suggest that a knowledge source existed for

these observers.

The Change X Group graph can be interpreted in such a manner. For the structured group the three negative changes have performance levels which reflect their absolute change. However, the positive change has a greatly reduced performance level. It should be remembered that the one positive change represents twice the number of observations as any negative change, making the overall ratio of negative changes to positive changes in the experiment 3:2. In addition, two of the three negative changes were of a larger magnitude than the positive changes. From the difference in number and magnitude one can conclude that the negative changes contained more information than the positive changes. From the graph it is obvious that observers in the structured condition did very well on the negative changes. This suggests that these observers were able to focus on the aspects of change most likely to maximize performance, presumably through a knowledge source provided by pattern structure.

These specific aspects of performance, along with the overall superiority, indicate that observers in the structured condition were able to abstract knowledge from the structure of the patterns, thereby gaining information and improving performance. Before speculating about the exact nature of the knowledge source though, Watson's findings and the experimental task need to be discussed.

Using the same paradigm with highly trained (i.e., greater than 15 hrs) observers Watson has found that the overall "uncertainty" of how the target tone can vary influences the listener's ability to resolve patterns. As indicated above, Watson et al. (1976) identified four factors which determine stimulus "uncertainty": 1) the number of patterns, 2) the number of target tone positions, 3) the number of target tone frequencies, and 4) the temporal

position of the target tone. When these "uncertainty" variables were held to a minimum several perceptual changes occurred: a) the sequence separated into 2-3 segments composed of elements close in frequency, similar to Bregman's "auditory streaming" effect; b) the stream containing the target tone, and especially the target tone itself increased in salience; c) the loudness of the target tone and its stream likewise increased.

These perceptual changes occur only when observers can focus their attention (i.e., when "uncertainty" is at a minimum). Even with an auditory pattern as short as the one employed in this paradigm listeners can focus their attention throughout its length. When observers are forced to search the entire pattern for the tone subject to change, their performance suffers. However, when observers know where they should be listening, performance is only slightly less than expected for isolated tones of equal duration (Watson et al., 1976).

For the structured and random conditions the four factors constituting stimulus uncertainty were held constant. The only difference was in the structuring of the elements which composed a sequence in the structured condition. This structuring facilitated the focus of attention; the difference between groups was due to a difference in ease of attentional focusing.

This focusing can be attributed to several aspects of the stimuli. For the structured condition the tones prior to the target tone were ascending in frequency and later tones were descending in frequency. Knowing that the target tone was sandwiched between these two runs helped observers locate the exact location of change. This is an obvious consequence of the rules applied to provide structure.

A not-so-obvious consequence has to do with the auditory streaming effect. Watson, Kelly and Wroton (1976) indicate that the tonal patterns separated into

2-3 streams during the course of experimentation and that the stream containing the target tone increased in salience. In the present experiment, the rules which provided the structure also placed the elements forming the target stream consistently in the middle of the pattern. Thus observers could utilize both the overall configuration of rising and falling frequency and the centralized streaming to focus attention. This constitutes the knowledge source employed in top-down processing.

Several qualifications need to be made in comparing the results of this study to Watson's findings. Although the stimuli were altered only by the addition of one tone and slightly larger differences, the training was substantially different. Watson's observers were trained for longer periods of time, typically a minimum of 15 hrs before any data were collected. Although the stimulus uncertainty was reduced to a minimal level and the training program was designed to facilitate frequency discrimination skills, observers in the present study had only one and one-half hrs of training before data were collected. The results may represent the lower end of the learning curve and any comparison to Watson's findings must be interpreted with this in mind.

Another qualification of the results must be made. This is due to the fact that 1 of 6 test trials designated as different (1 of 12 experimental trials) was actually the same, and false feedback was given each time that that specific different trial was presented. Although this seems like a major problem, several factors mitigate its impact. First, the nature of psychoacoustic studies implies uncertainty. In this experiment the changes in frequency were small and training was necessary for listeners to detect these differences. Even with this training listeners in the random condition averaged only 52.2% across all trials: only 2.2% above chance. Obviously on the 11 of 12

experimental trials with correct feedback these observers had trouble discriminating between same and different trials anyway.

A look at the data from the remaining two groups suggests that if anything, the incorrect feedback reduced the size of the experimental effect. The same errors were present for all the groups and while the random group remained barely above chance the structured and constant groups were able to make discriminations. The structured group averaged 69% across all trials; the constant group averaged 60%. One can assume that correction of the feedback error would have facilitated performance in these two groups relative to the random condition.

Summary and Practical Implications

The size of frequency changes employed in the experiment was highly significant and represents appropriate difference magnitudes for the task. Performance was generally related to the absolute frequency change, although in some instances a selective bias may have occurred. The predicted effect due to musical training did not occur. Contributing factors may be the lack of stringent criteria for inclusion in the training group, the extremely short duration times of tones, and the lack of musical structure. The main finding of the study is that the structure of contextual tones can provide a knowledge source to facilitate frequency discrimination. The final group performance rankings are (from best to worst): structured, constant, and random. This is somewhat surprising. The predicted difference between the structured and random conditions was significant, but the predicted ordering of the structured and constant conditions was reversed. It appears that the structured group was able to abstract information which influenced the ability to focus attention on relevant aspects of the pattern.

In real world auditory monitoring tasks such as passive sonar, listeners must identify the source of sounds and learn as much as possible about what the target object is doing. These sounds often occur in sequences or patterns in which a temporal structure or sound order can provide important information about the event being monitored. As listeners gain familiarity with the sound patterns in a particular environment, they will be able to direct limited-capacity attentional resources to the most important aspects of the pattern. The present experiment illustrates that a structural knowledge source can play an important role in attentional focusing when individual elements must be resolved from within multicomponent patterns. Pattern-related structural information will become even more important when the meaningful pattern components are difficult to resolve and/or occur at a very low signal-to-noise ratio. In such a situation, component ambiguity can sometimes be resolved by reference to the pattern structure.

REFERENCES

Attneave, F. & Olson, R. K. Pitch as a medium: A new approach to psychophysical scaling. American Journal of Psychology, 1971, 84, 147-166.

Bartlett, J. C. & Dowling, W. J. Recognition of transposed melodies: A key-distance effect in developmental perspective. Journal of Experimental Psychology: Human Perception and Performance, 1980, 6, 501-515.

Bastian, J., Eimas, P. D., & Liberman, A. M. Identification and discrimination of a phonetic contrast induced by a silent interval. Journal of the Acoustical Society of America, 1961, 33, 842.

Bregman, A. S. The formation of auditory streams. In J. Requin (Ed.), Attention and performance VII. Hillsdale, N. J.: Erlbaum, 1978.

Bregman, A. S., & Campbell, J. Primary auditory stream segregation and perception of order in rapid sequences of tones. Journal of Experimental Psychology, 1971, 89, 244-249.

Cuddy, L. L. Practice effects in the absolute judgment of pitch. Journal of the Acoustical Society of America, 1968, 43, 1069-1076.

Cuddy, L. L. Absolute judgment of musically-related pure tones. _Canadian Journal of Psychology_, 1971, _25_, 42-55.

Cuddy, L. L., & Cohen, A. J. Recognition of transposed melodic sequences. _Quarterly Journal of Experimental Psychology_, 1976, _28_, 255-270.

Cuddy, L. L., Cohen, A. J., & Mewhort, D. J. K. Perception of structure in short melodic sequences. _Journal of Experimental Psychology: Human Perception and Performance_, 1981, _7_, 869-883.

Cuddy, L. L., Cohen, A. J., & Miller, J. Melody recognition: The experimental application of musical rules. _Canadian Journal of Psychology_, 1979, _33_, 148-157.

Deutsch, D. Memory and attention in music. In M. Critchley & R. A. Henson (Eds.), _Music and the brain_. Springfield, Il.: Charles C. Thomas, 1977.

Deutsch, D. The processing of structured and unstructured tonal sequences. _Perception & Psychophysics_, 1980, _28_, 381-389.

Dowling, W. J. Scale and contour: Two components of a theory of memory for melodies. _Psychological Review_, 1978, _85_, 341-354.

Dewar, K. M., Cuddy, L. L., & Mewhort, D. J. K. Recognition memory for single tones with and without context. _Journal of Experimental Psychology: Human Learning & Memory_, 1977, _3_, 60-67.

Glass, A. L., Holyoak, K. J., & Santa, J. L.   Cognition.

Reading, Mass.: Addison-Wesley, 1979.

Green, D. M., & Swets, J.   Signal detection theory and

psychophysics. New York: Wiley, 1966.

Guilford, J. P., & Hilton, R. A. Some configural

properties of short musical melodies. Journal of

Experimental Psychology, 1933, 16, 32-54.

Guilford, J. P., & Nelson, H. M. Changes in the pitch of

tones when melodies are repeated. Journal of

Experimental Psychology, 1936, 19, 193-202.

Heise, G. A., & Miller, G. A. An experimental study of

auditory patterns. American Journal of Psychology, 1951,

64, 68-77.

Howard, J. H., Jr., & Ballas, J. A. Syntactic and

semantic factors in the classification of nonspeech

transient patterns. Perception & Psychophysics, 1980,

28, 431-439.

Idson, W. L., & Massaro, D. W. Cross octave masking of

single tones and musical sequences: The effects of

structure on auditory recognition. Perception &

Psychophysics, 1976, 19, 155-175.

Krumhansl, C. L., & Shepard, R. N. Quantification of the hierarchy of tonal functions within a diatonic context. Journal of Experimental Psychology: Human Perception and Performance, 1979, 5, 579-594.

Lesser, V. R., Fennell, R. D., Erman, L. D., & Reddy, D. R. Organization of the HEARSAY II speech understanding system. IEEE Transactions on Acoustics, Speech , and Signal Processing, 1975, 23, 11-24.

Liberman, A. M., Cooper, F. S., Shankweiler, D., & Studdert-Kennedy, M. Perception of the speech code. Psychological Review, 1967, 74, 431-461.

Marslen-Wilson, W. D. Sentence perception as an interactive parallel process. Science. 1975, 189, 226-228.

Marslen-Wilson, W. D., & Tyler, L. K. The temporal structure of spoken language understanding. Cognition, 1980, 8, 1-71.

Marslen-Wilson, W. D., & Welsh, A. Processing interactions and lexical access during word recognition in continuous speech. Cognitive Psychology, 1978, 10, 29-63.

Massaro, D. W. Preperceptual auditory images. Journal of Experimental Psychology, 1970, 85, 411-417.

Miller, G. A., & Heise, G. A. The trill threshold. Journal of the Acoustical Society of America, 1950, 22, 637-638.

Reber, A. S. Transfer of syntactic structure in synthetic

languages. Journal of Experimental Psychology, 1969, 81,

115-119.

Reber, A. S. Implicit learning of synthetic languages:

The role of instructional set. Journal of Experimental

Psychology: Human Learning & Memory, 1976, 2, 88-94.

Reber, A. S., & Allen, R. Analogic and abstraction

strategies in synthetic grammar learning: A

functionalist interpretation. Cognition, 1978, 6,

189-221.

Reber, A. S., & Lewis, S. Implicit learning: An analysis

of the form and structure of a body of tacit knowledge.

Cognition, 1977, 5, 331-361.

Reddy, D. R. Speech recognition by machine: A review.

Proceedings of the IEEE, 1976, 64, 501-531.

Reddy, D. R., Erman, L. D., & Neely, R. B. A model and a

system for machine recognition of speech. IEEE

Transactions on Audio and Electroacoustics, 1973, 21,

229-238.

Spiegel, M. F., & Watson, C. S. Factors in the

discrimination of tonal patterns. III. Frequency

discrimination with components of well learned patterns.

Journal of the Acoustical Society of America, 1981, 69,

223-230.

Warren, R. M. Perceptual restoration of missing speech
sounds. Science, 1970, 167, 392-393.

Warren, R. M., & Warren, R. D. Auditory illusions and
confusions. Scientific American, 1970, 223, 30-36.

Watson, C. S., Kelly, W. J., & Wroton, H. W. Factors in
the discrimination of tonal patterns. II. Selective
attention and learning under various levels of stimulus
uncertainty. Journal of the Acoustical Society of
America, 1976, 60, 1176-1186.

Watson, C. S., Wroton, M. W., Kelly, W. J., & Benbassat,
C. A. Factors in the discrimination of tonal patterns.
I. Component frequency, temporal position, and silent
intervals. Journal of the Acoustical Society of America,
1975, 57, 1175-1185.

FOOTNOTE

[1] The study was originally designed to have 6 frequency changes: −64, −48, −32, +32, +48, or +64 Hz. A programming error resulted in only 5 changes being played. One trial designated as a "different" or a target pattern was actually the same; thus all listeners were given false feedback once every 12 trials on the average. A related error repeated one change two times; this error resulted in only 4 magnitudes of frequency change, −64, −48, −32, and 32 Hz, being presented and the positive change played twice.

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